



# Performance of permeable surfaces

*Michael Borst, Chemical Engineer*

**On paper, green infrastructure appears to be a cost effective stormwater management solution.**



# How well does green infrastructure perform (now and years from now)?

- What is the design sizing guidance?
  - What does it cost to design and build?
  - How well does it meet design objectives?
  - How do I know that it is meeting the objectives?
  - What maintenance is needed and how often?
  - How do I know when to do the maintenance?
  - Of the available options where do I install it?
  - How many do I need to meet my overall basin objectives?
  - How do I know that I am meeting basin-wide objectives?
  - How do I model the GI?
- 
- What else do I get for the investment?



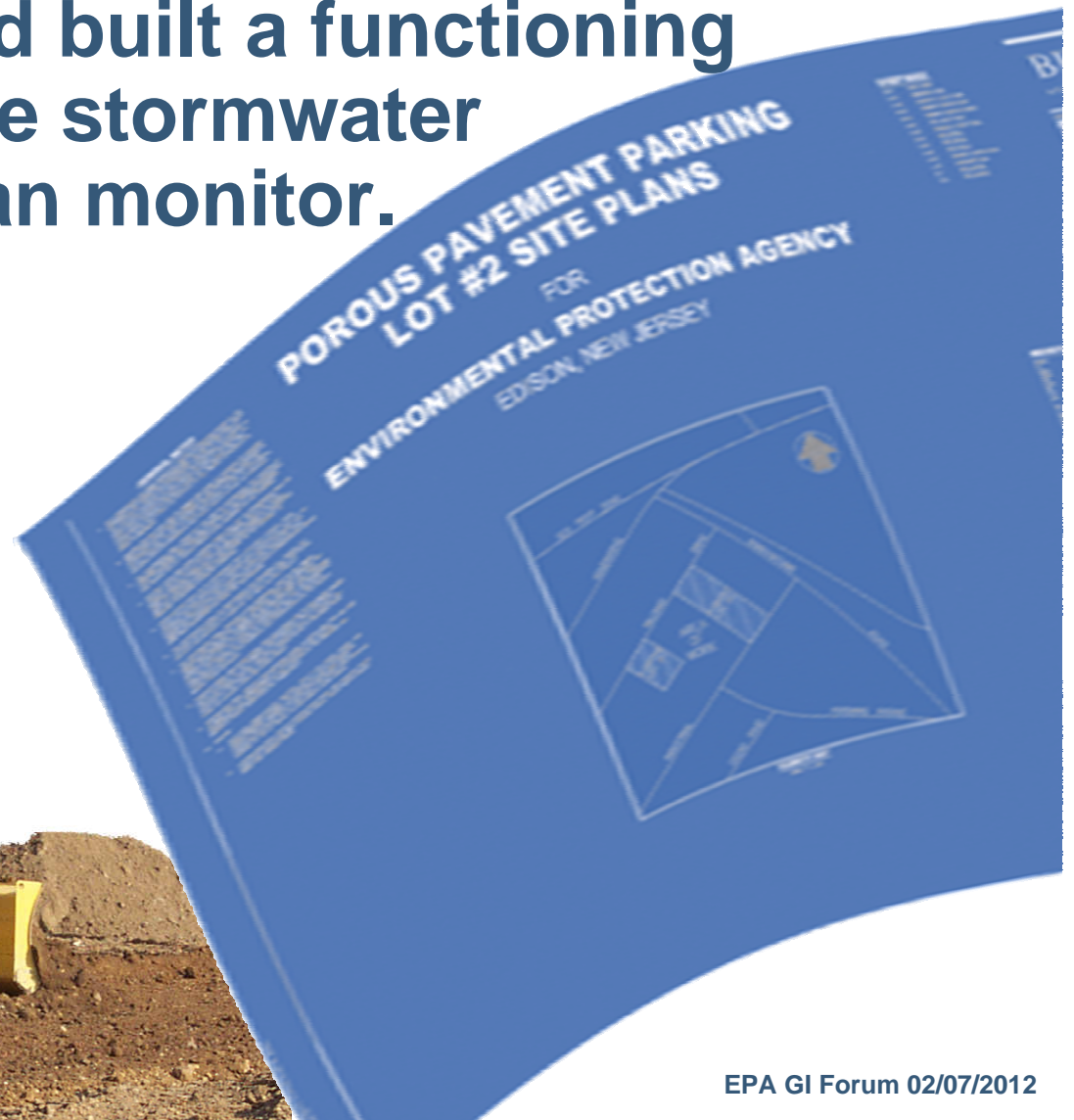
S. Sepp Wikipedia.org

**To begin to answer these questions, we need to combine field and controlled-condition research.**





**EPA designed and built a functioning permeable surface stormwater control that we can monitor.**



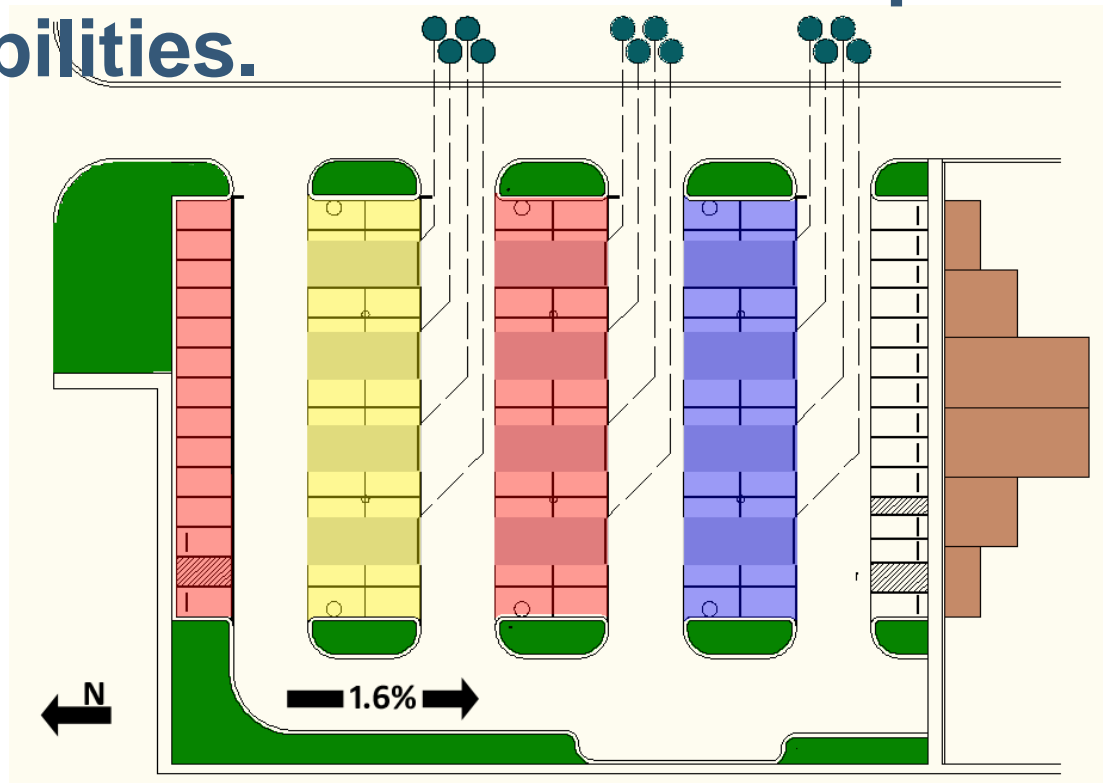


**We invited the trade groups to review and comment on the design plans and to be on site for installation.**

**We also required that the suppliers and installers had the trade group's certifications**



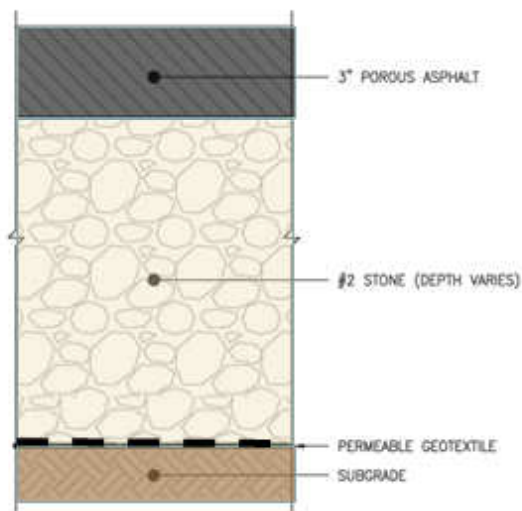
# The final design incorporates three permeable surfaces and unique monitoring capabilities.



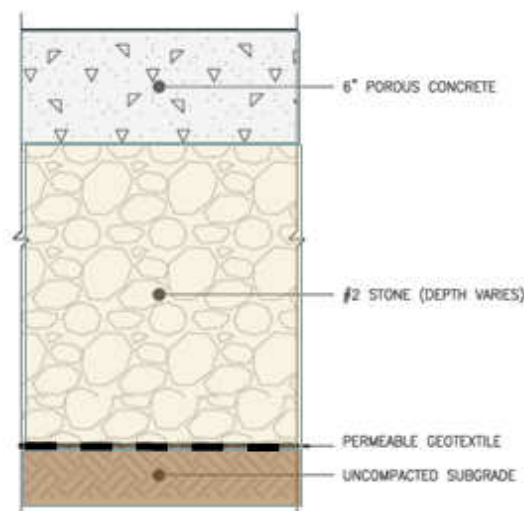
- Interlocking concrete pavers
- Porous concrete
- Porous asphalt
- Conventional asphalt
- Buried distribution pipes
- Collection tanks
- Rain gardens
- Tree islands

# Vertical cross sections of permeable sections vary slightly from material to material

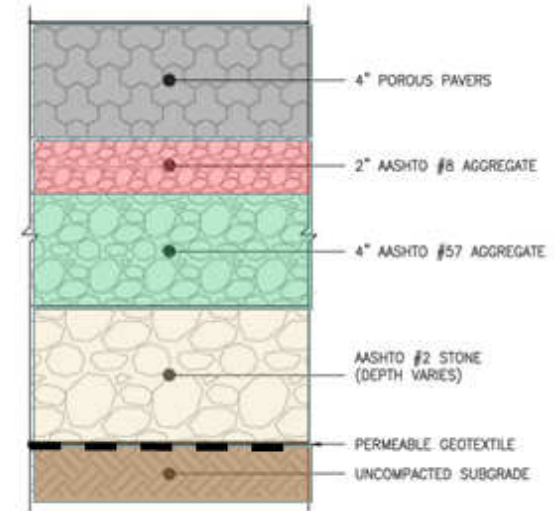
Not to scale



Porous  
Asphalt



Porous  
Concrete



Interlocking  
Concrete  
Pavers

\* Courtesy of Morris Ritchie and Associates, 2009



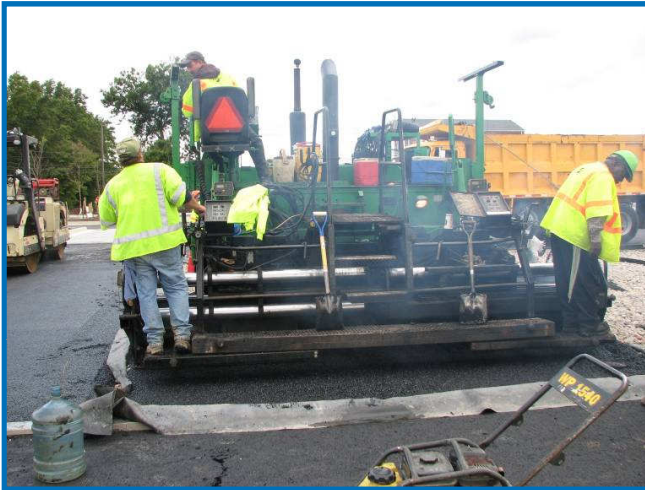
# Interlocking concrete paver installation took a little more than a week.



## Porous concrete pour took two days followed by a week of covered cure time.



# Placing the porous asphalt took two days



# The construction recycled the demolished concrete



Demolition of existing  
concrete surface



Clearing



Crushing  
and  
screening  
to No. 2  
sized stone



Excavating the storage volume.

**The recycled concrete aggregate was placed over a geotextile to form the storage layer before installing the wearing course.**

Geotextile placed at interface to underlying soil



#2 stone added from North to South and compacted with 20-ton non-vibratory roller.



Asphalt and concrete placed directly on the #2 stone. Pavers required choking and bedding layers



EPA GI Forum 02/07/2012



# Overall, construction took about a year.

November 26, 2008



February 26, 2009



March 25, 2009



June 1, 2009



August 5, 2009



October 6, 2009

October 8, 2009

October 28, 2009

**Parking area is largely filled during work day by facility staff and visitors.**



**The appearance of the porous surfaces during a rain event clearly delineates the edge.**



## The most popular question is about infiltration rates.

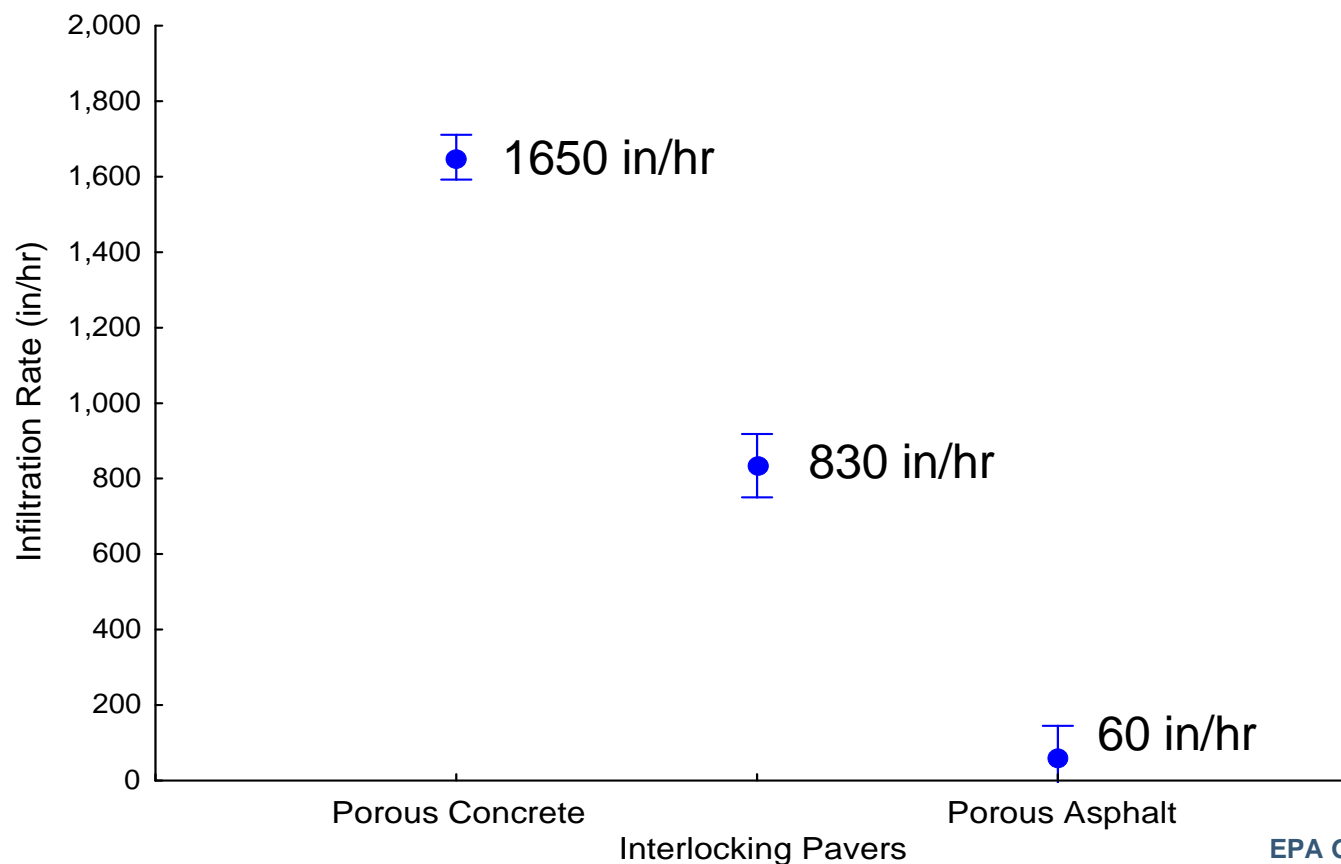
We measure infiltration rate at three randomly selected locations on each half of each surface monthly.



Modified ASTM C1701 apparatus

# The infiltration rate measured using modified ASTM C1701 varied across the surfaces

Current effect:  $F(2, 440)=478.87, p<0.0001$   
Vertical bars denote 0.95 confidence intervals





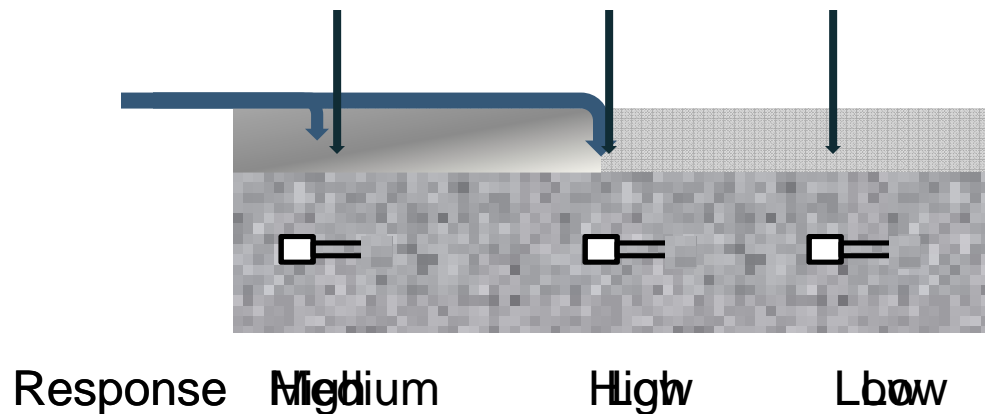
## The surface clogging does not result from uniform distribution of solids across the surface



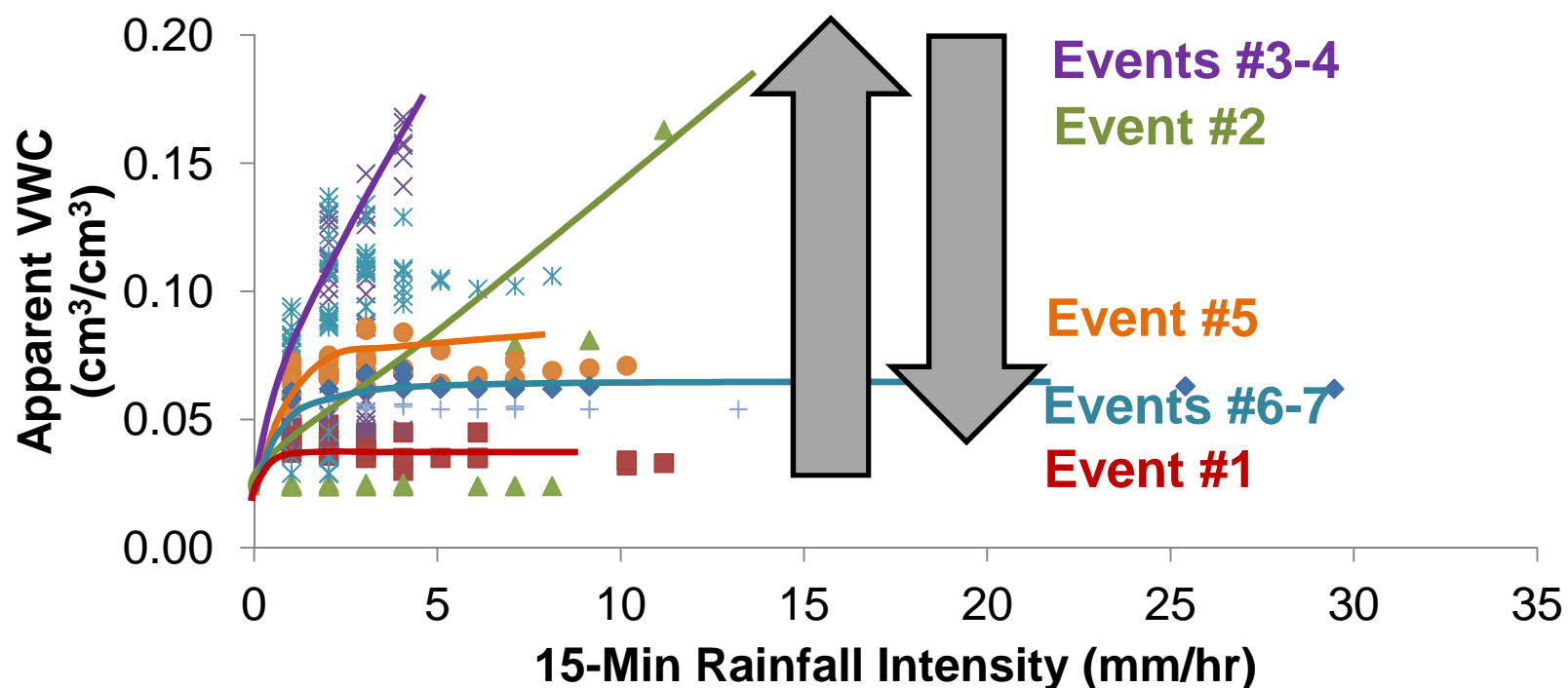
## Time Domain Reflectometers (TDRs) were developed to measure moisture under crops and turf grass to help assure efficient irrigation



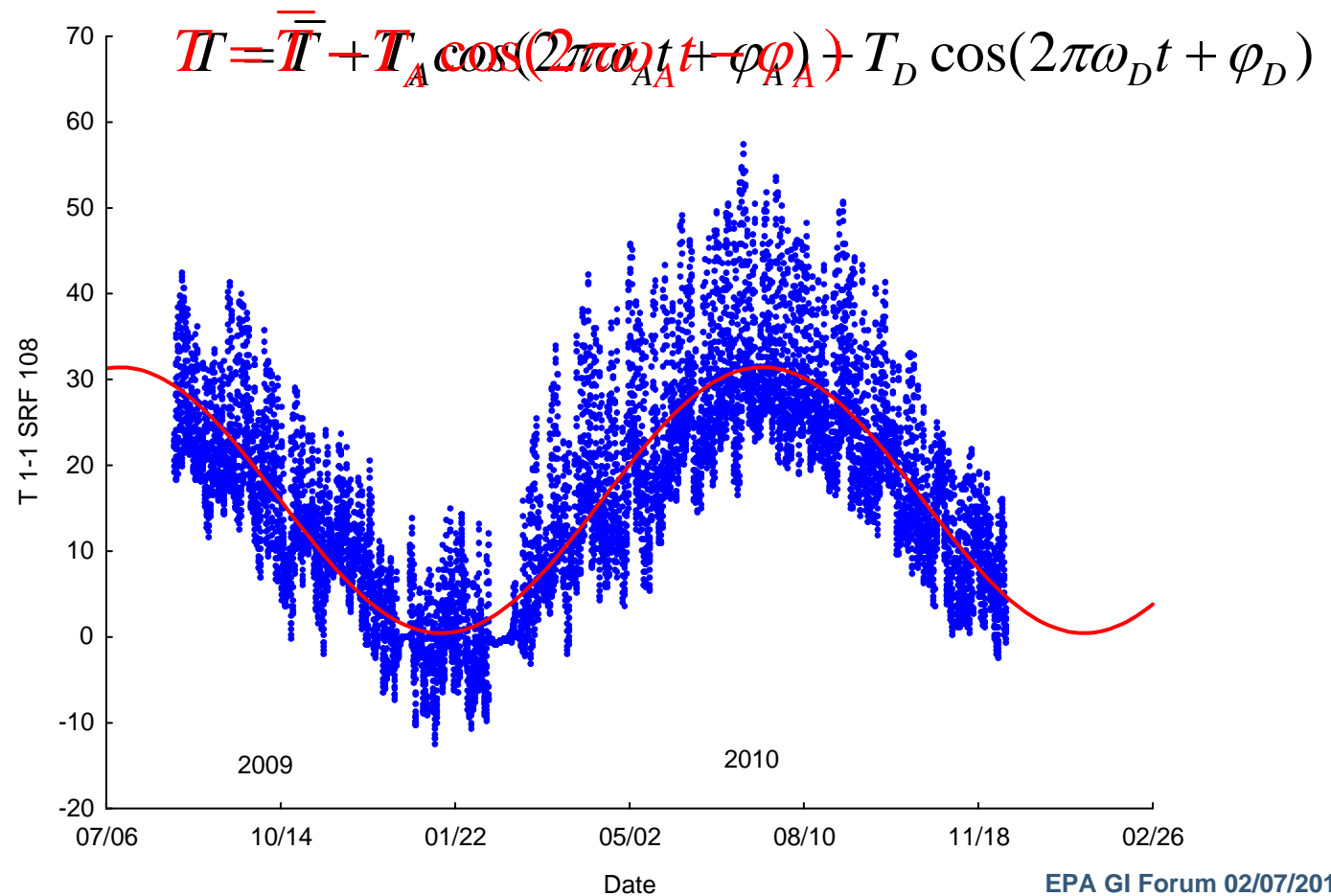
**We installed TDRs near the surface at locations to indicate if surface clogging was occurring and to measure its progression**



## TDR Response to the varying rain intensity can be used to measure and track surface clogging.



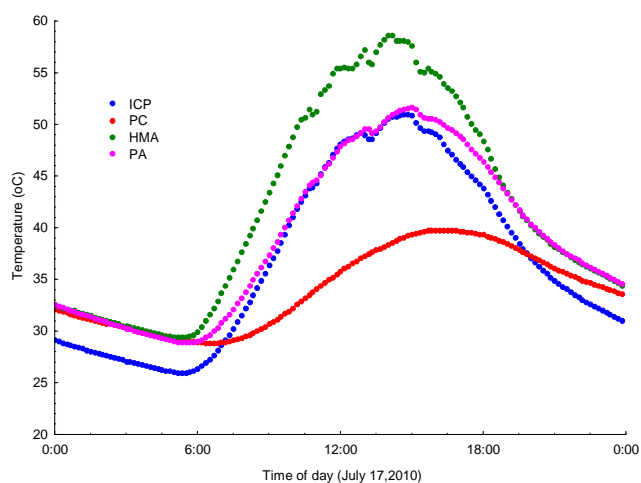
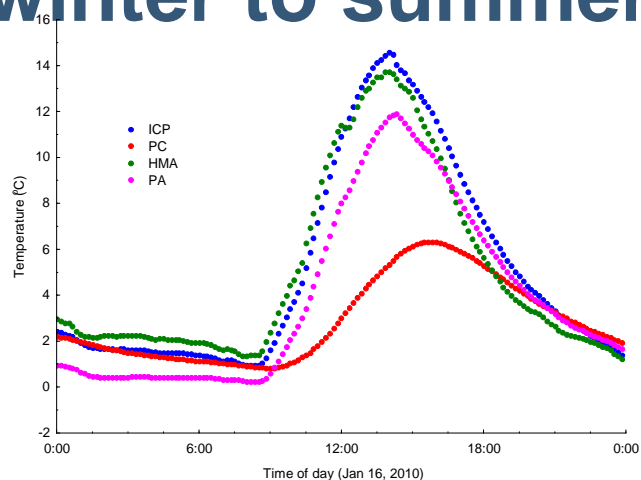
## There is ongoing interest in permeable surfaces as “cool pavement” material.



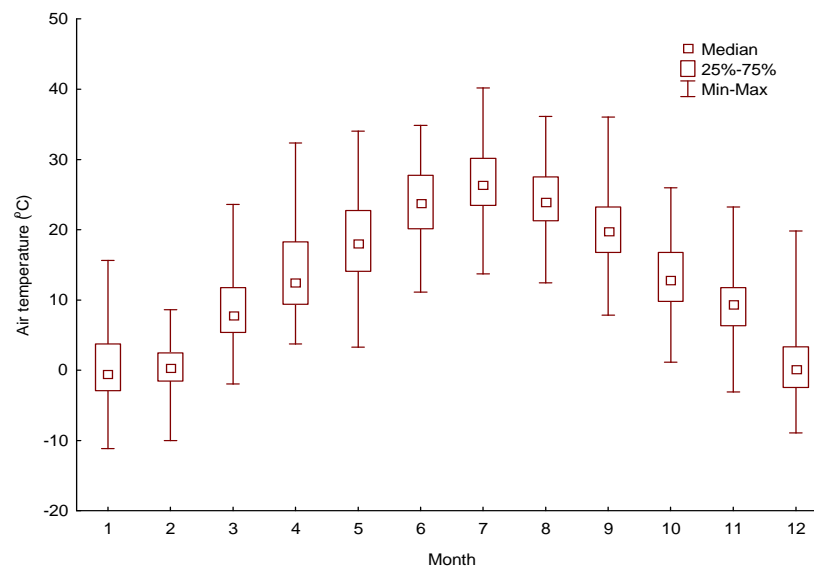
**The preliminary results suggest differences in mean annual surface temperature and in annual fluctuations across permeable surfaces.**

Media	$\bar{T}$ (°C)	$T_A$ (°C)	$1/\omega_a$ (day)	$\phi_a$ (day)
ICP	14.9	15.5	362.8	90.68
PC	15.6	15.8	362.4	90.69
PA	16.3	15.7	369.3	90.59
HMA*	19.9	18.8	365.2	90.59
SOIL†	14.3	14.3	369.3	90.62
AIR	13.4	13.0	365.8	90.65

## Daily patterns show some differences winter to summer.



Minimal cloud cover days from incident light measures



For monitored period to date:

Month with smallest median temperature January  $-0.6^{\circ}\text{C}$

Month with largest median temperature July  $26.5^{\circ}\text{C}$

Porous concrete has largest lows and it reaches its maximum and minimum temperatures latest in the day

# Owning the property provides control over the maintenance and maintenance levels.



[www.fnal.gov](http://www.fnal.gov)

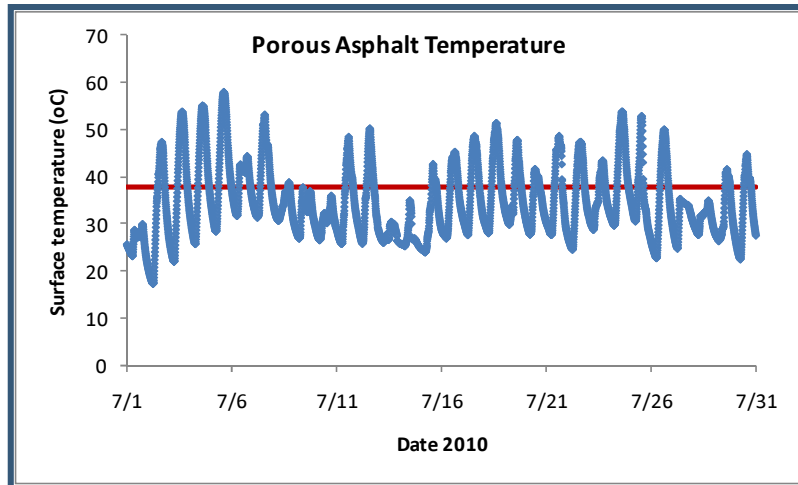


[www.barrowbc.gov.uk](http://www.barrowbc.gov.uk)

It might work in New Jersey, but it ...  
... snows here.



... is hot here.



## A few places in the porous concrete disaggregated.



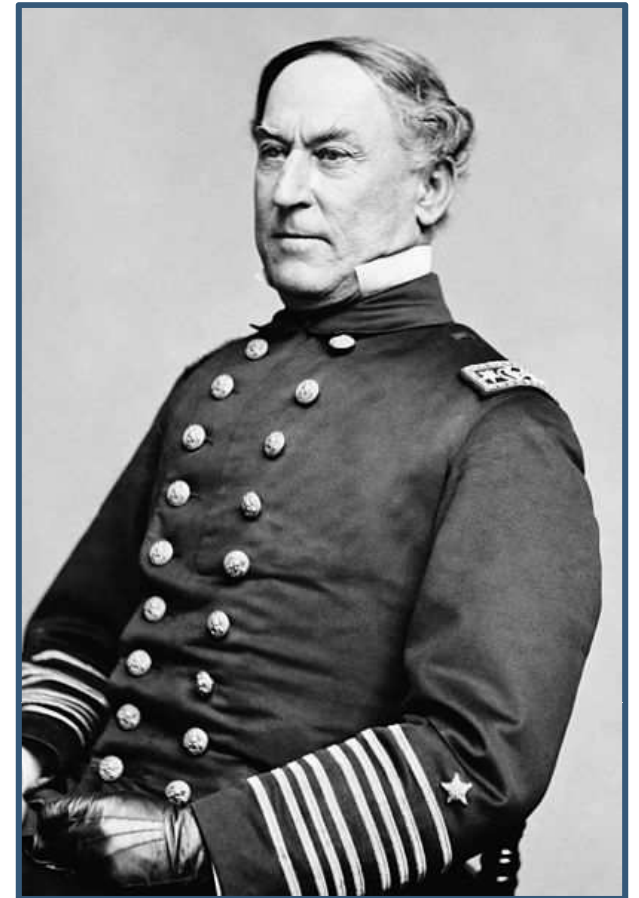
Roughly 28 inch across

Roughly 3 inch deep

Total less than 5% of area covered by porous concrete.  
Suspect dirty aggregate prevented good concrete bonding.  
Became apparent about 18 months after pouring concrete.

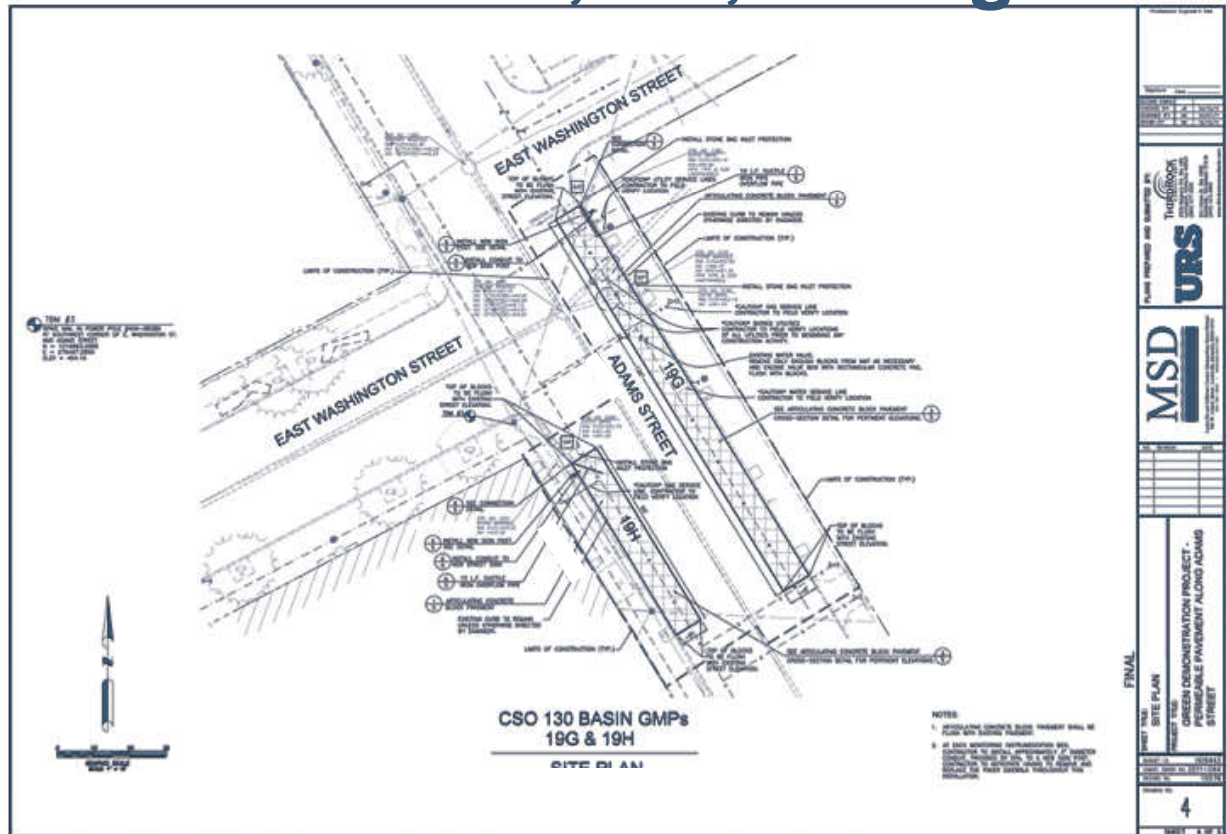
## Destructive investigation showed the failed sections had formed separate



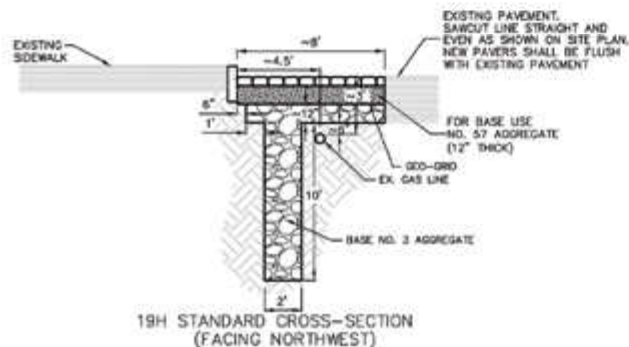


# MOVING INTO THE REAL WORLD

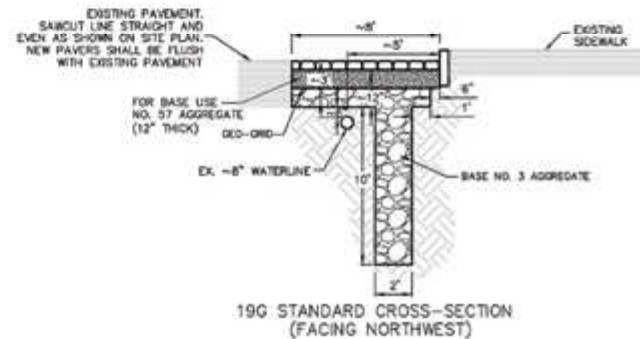
Two articulated paver strips were installed at the corner of East Washington and Adams Streets in Louisville, KY, during Dec. 2011.



**Off-center trenches were installed to access soil with higher hydraulic conductivity and avoid existing utilities.**



**2** **ARTICULATING CONCRETE BLOCK CROSS-SECTION**  
5 NOT TO SCALE



**3** **ARTICULATING CONCRETE BLOCK CROSS-SECTION**  
5 NOT TO SCALE

## Within CSO 130, permeable pavement is the preferred technique.

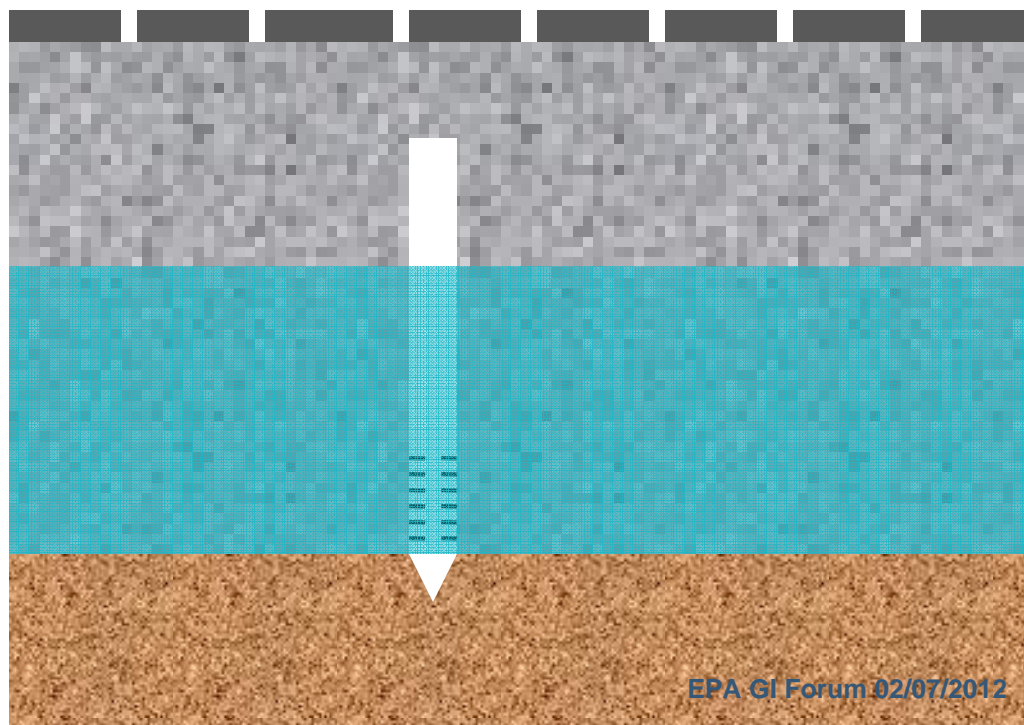
The limited publically-owned property and generally narrow sidewalks forced the controls into the streets.



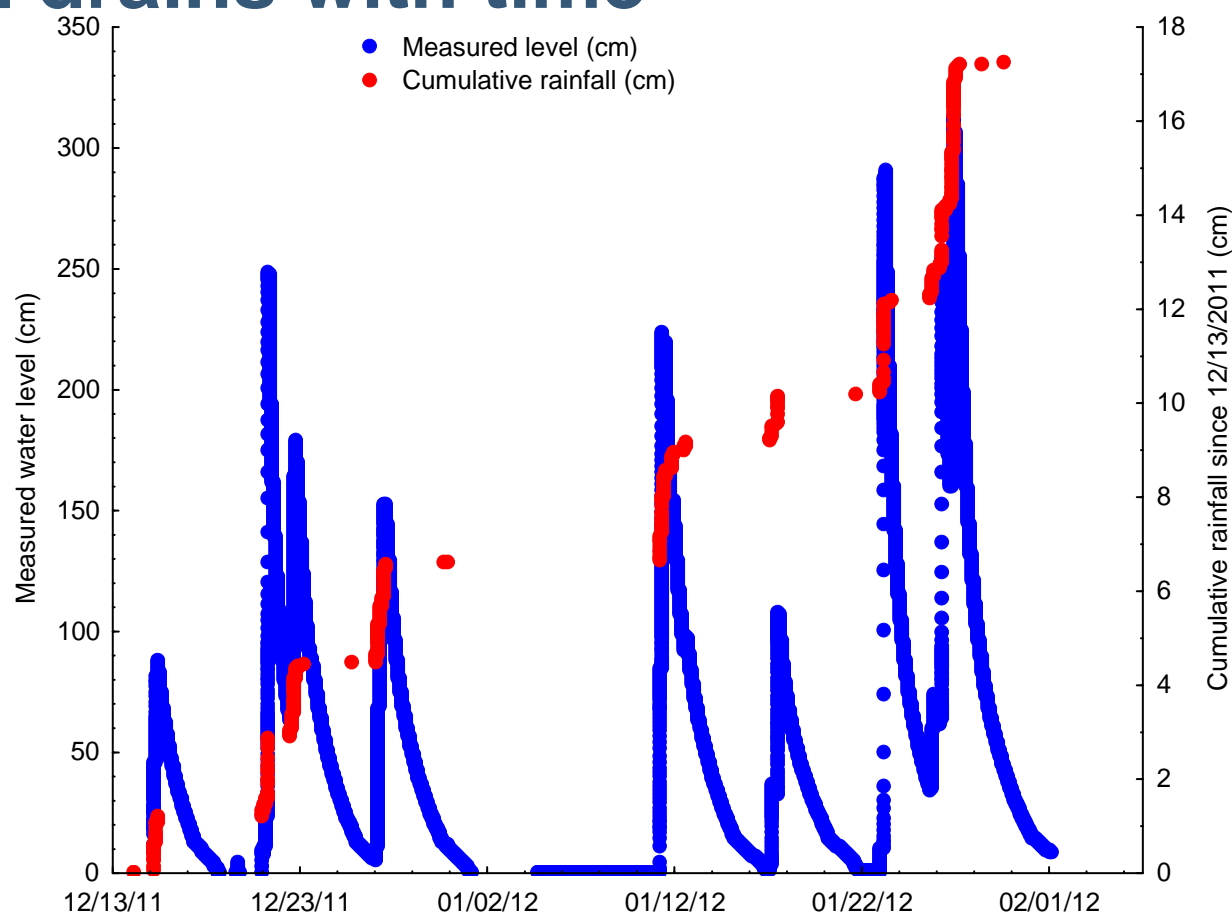
## We installed the pressure transducers in the piezometers to measure the accumulation and infiltration (rise and fall) of captured water

The fill rate is controlled by rainfall intensity while drain is controlled by saturated infiltration rate.

Depth (volume) is controlled by depth of rainfall, dimension, porosity and infiltration during event.



## The water level in the control rises with rainfall and drains with time





**Everyone asks what it costs. I don't know what it costs, but I know what was quoted for the Edison project.**

Pavement	Paved Area (sq ft)	Quote (\$)		Quote (\$/sq yd)	
		Largest	Smallest	Largest	Smallest
Hot Mix Asphalt	36,225	98,600	92,620	24.50	23.01
Porous Asphalt	5,328	28,650	18,352	48.40	31.00
Permeable Pavers	5,328	67,960	61,755	114.80	104.32
Porous Concrete	7,988	63,200	53,919	71.21	60.75

Final proposed costs reported by S&E Services, Inc, June 15,2009

Costs include material and installation of surface over EPA-prepared storage layer for PA and PC

Costs include layers of #57 and #8 for pavers in addition to pavers and installation

Quotes June 2009 Edison, NJ



## Costs in Louisville for 1,400 square ft (2 controls).

Item	Quantity	Cost (\$)	Fraction (%)	
# 57 Aggregate	52 CY	3,172	6.6	
Geogrid	1400 SF	5,600	11.6	
Pavers	1400 SF	19,600	40.6	\$126/sq yd
Earthwork	235 CY	8,225	17.1	
#3 Aggregate	181 CY	7,240	15.0	
Overflow pipe	LS	1,200	2.5	
Asphalt removal	1400 SF	1,050	2.2	
Traffic control	LS	600	1.2	
Survey & stake	LS	200	0.4	
Erosion / sediment control	LS	200	0.4	
Bonding	LS	650	1.3	
Mobilization / Demobilization	LS	500	1.0	
<b>Total</b>		<b>\$48,237</b>	<b>100</b>	<b>\$310/sq yd</b>

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